Chapter 9: Value of Information

One of the advantages of a decision analysis approach is that it facilitates the analysis of sequential decision, especially those that involve the collection of information before making a final decision. For example, the decision tree in Figure 9.1 can easily be expanded to include an action "Wait for more EMF research, before making a decision," followed by the resolution of uncertainties about the outcomes of EMF research, followed by the second decision about selecting a mitigation option, if any. This type of analysis is known as value-of-information (VOI) analysis.
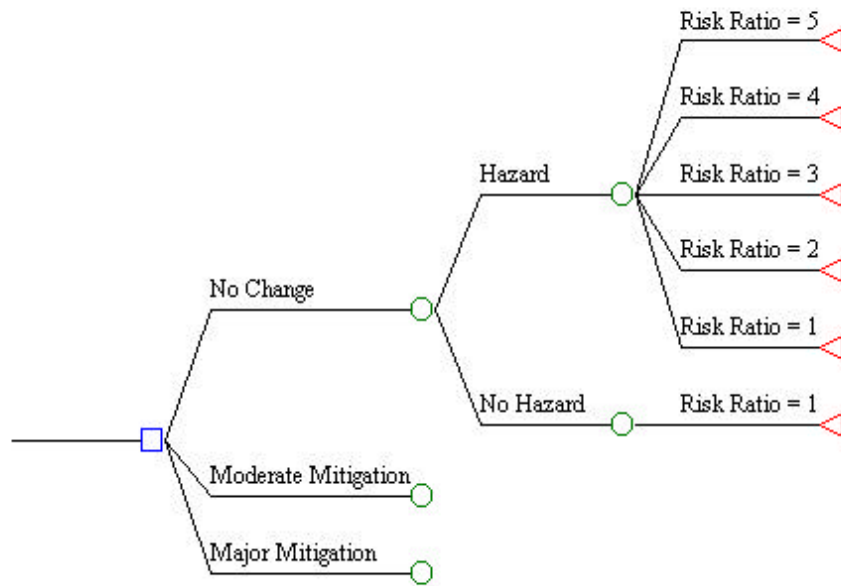

Figure 9.1: Schematic Decision Tree for Policy Analysis

In the early phases of this project, we had envisioned to include a VOI analysis in all decision analysis models. We discarded this strategy for two reasons. First, the number of models and the level of detail required for each model grew much larger than we had anticipated; including a decision node "Wait for Research" would have substantially increased the complexity of each model. Second, Analytica is not very well designed to handle value-of-information calculations; as a consequence, a significant additional programming effort would have been required for a VOI analysis.

Instead of conducting a VOI analysis for each model, we chose to develop a more general VOI analysis tool that considers the value of EMF research not for a specific decision problem, but for supporting EMF research in the United States. The development

of this tool was initially funded by the Electric Power Research Institute. The adaptation of this tool for this project was funded by the California Department of Health Services.

In the following sections, we will first illustrate the concepts and calculations of a VOI analysis with the home grounding scenario. Subsequently, we present the national VOI model and its results (see also Appendix F). The final section will draw some conclusions from applying the national model to California.

9.1 Illustration of VOI concepts with the Home Grounding Model

We consider a simplified version of the home grounding scenario A (see Chapter 8), in which the homeowner considers only two alternatives: "No change" or "Insulate the Pipe," as represented in the decision tree in Figure 9.2.
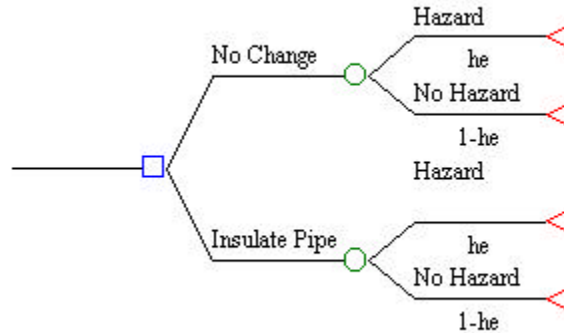

Figure 9.2: Simplified Decision Tree for the Home Grounding Problem

In this tree he stands for the probability that EMF exposure poses a hazard. The consequences at the end of the tree are health effects (measured in life-years lost) and the cost of insulating the pipe (measured in 1998 dollars). Using the results of section 8.4, these consequences are described in Table 9.1. The cost of insulating the pipe is set at a low level, based on von Winterfeldt and Trauger (1996).

Table 9.1: Consequences for the Home Grounding Problem

	Health	Cost
No Change		
Hazard	0.0694	$0
No Hazard	0	$0
Insulate Pipe		
Hazard	0	$210
No Hazard	0	$210

Using $100,000 as the equivalent cost of one lost year of life expectancy, we can express the health consequences in 1998 dollars, as shown in Table 9.2. By putting the total equivalent costs at the end of the decision tree in Figure 9.1, we can then calculate the expected equivalent costs at the rot node of the decision tree as follows:

Equivalent Cost (No Change) = he*6,940+(1-he)*0,
Equivalent Cost (Insulate Pipe) = he*0+(1-he)*210.

Table 9.2: Equivalent Costs for the Home Grounding Problem

	Health	Cost	Total
No Change			
Hazard	$6,936	$0	**$6,936**
No Hazard	$0	$0	**$0**
Insulate Pipe			
Hazard	$0	$210	**$210**
No Hazard	$0	$210	**$210**

For he=0.10, the results are $2,061 and $1,795, respectively, as shown in the "solved" decision tree of Figure 9.3 (see also the results in Chapter 8). Thus, given the assumptions and parameters of this problem, insulating the pipe is better than to do nothing.

Figure 9.3: Solved Decision Tree for the Simplified Home Grounding Problem

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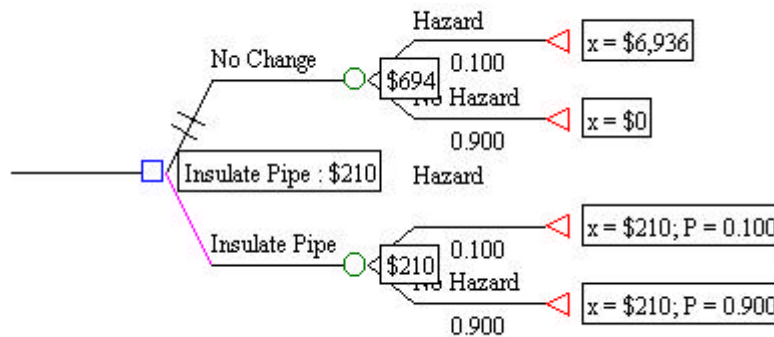
1. Now assume that the homeowner can get perfect information about whether EMF
2. exposure poses a hazard, and that this information does not cost anything and would be
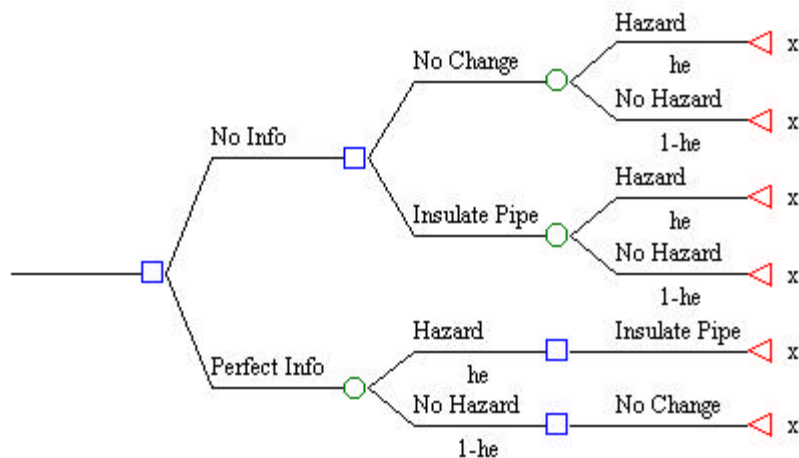3. available immediately. This case is represented as a decision tree in Figure 9.4.
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7.

8.
9.
10. **Figure 9.4: Decision Tree with Perfect Information**
11.
12.
13. The upper part of this tree is identical to Figure 9.2. In the lower part, the
14. homeowner finds out whether EMF exposure poses a hazard before making a decision.
15. Obviously, the best decision is to insulate the pipe, if there is a hazard, otherwise to do
16. nothing. How much better off is the home owner with perfect information than without?
17.
18. Figure 9.5 shows the solved decision tree for this perfect information problem. It
19. shows that acting with perfect information has an equivalent cost of $21 and that acting
20. without it has an equivalent cost of $210 (the expected cost of insulating the pipe). The
21. expected value of perfect information (EVPI) is the difference between these two costs or
22. $199. Thus, the homeowner should pay $199 to obtain perfect information about whether
23. or not EMF poses a hazard.
24.
25. While this may seem like a small amount for an individual homeowner, it
26. represents a significant value of perfect information for all home owners in California who
27. have a potential home grounding problem. There are about 10 million homes in
28. California, 10% of which may have elevated fields from net currents on water pipes.
29. Thus, the total value of perfect information in California alone would be $199 million,
30. given the assumptions made in this scenario.
31.

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1   Real information is not perfect. For one, real information never resolves
2 uncertainties completely, but it is likely to leave some lingering doubts. For another, real
3 information does not come immediately, but may take time, during which the negative
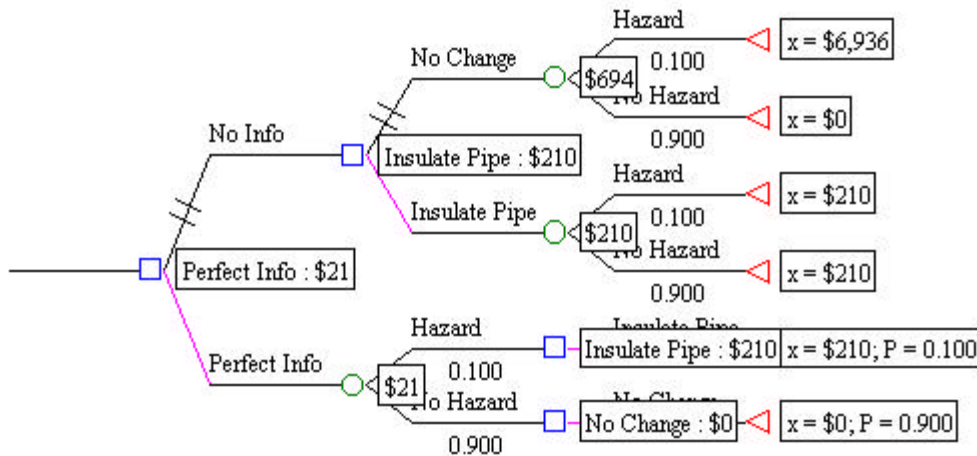4 consequences of not taking action can accrue. Figure 9.6 considers real or "sample"
5
6
7

8
9 **Figure 9.5: Solved Decision Tree with Perfect Information**
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11
12 information about the link between EMF exposure and health effects. The top part of this
13 figure represents the "No Change" alternative. The bottom part begins with collecting
14 sample information for a number of years. The question for the homeowner is: Should I
15 wait for y years until sample information becomes available, or should I act now and
16 insulate the pipe?
17
18   In this illustration, sample information within y years will produce positive results
19 with probability pr, proving conclusively that EMF exposure is a health hazard. It will
20 produce inconclusive results with probability, leaving that possibility that EMFs are a
21 hazard with probability hir or not (1-hir). Negative results have a probability of nr,
22 proving conclusively that EMFs pose no hazard.
23
24   Judging these probabilities is difficult. Often, it is easier to assess
25
26 q = Probability(Positive Research|Hazard),
27 r = Probability (Negative Research|No Hazard), and
28 he = Probability that EMF exposure poses a hazard,
29
30 and to calculate the probabilities shown in Figure 9.6 from these estimates using Bayes'
31 Theorem. For illustration, we use q=0.50, r=0.50, he=0.10. We also consider to wait for
32 one year. With these inputs we can solve the decision tree as shown in Figure 9.7.
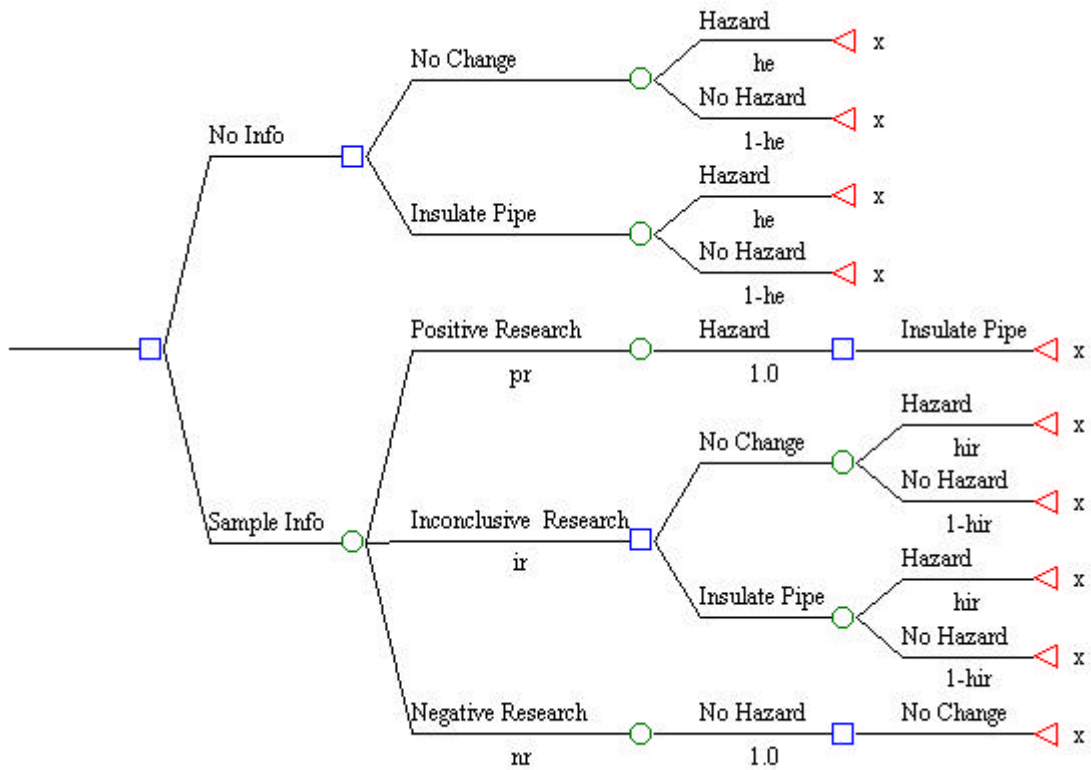33

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Figure 9.6: Decision Tree with Sample Information

The expected value of sample information (EVSI) is the difference between the expected cost of acting without information and of acting with it, which, in this case is $37. As a general rule, the expected value of perfect information is always higher than the expected value of sample information. Thus, the EVPI provides an upper bound for EVSI.
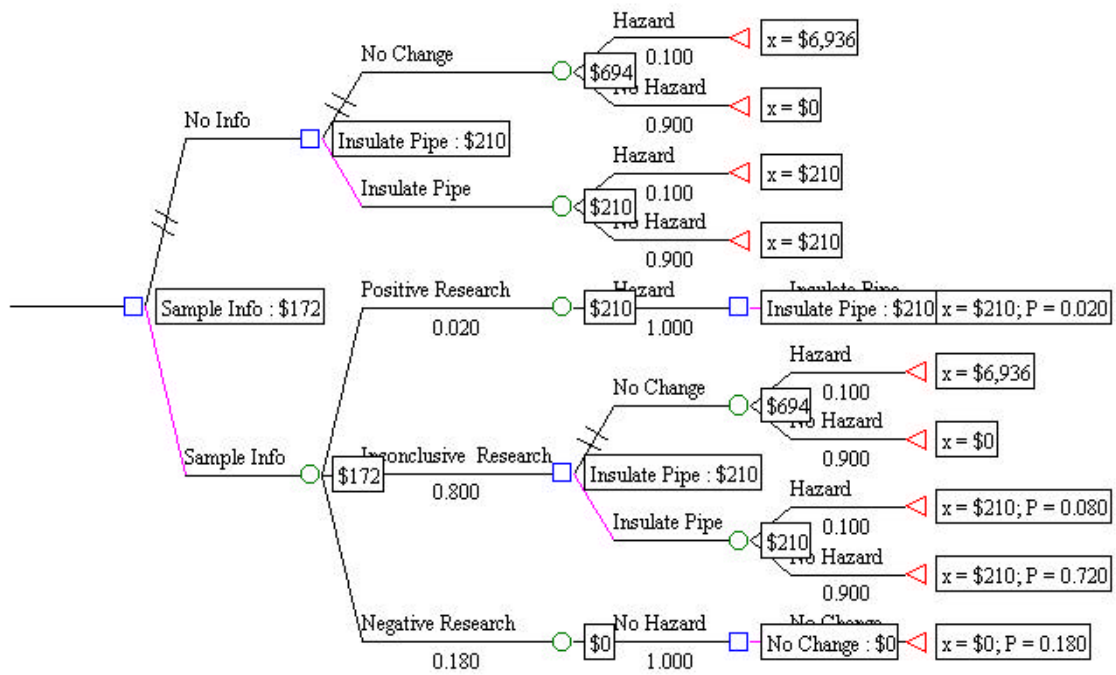
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Figure 9.7: Solved Decision Tree with Sample Information

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9.2 National VOI Analysis

The example in section 9.1 illustrated the concepts of value of information in a decision analysis. We extended these ideas to create a VOI model for EMF research in the United States. Rather than assuming specific scenarios about costs, health effects, probabilities, and other variables, we created a fully parameterized model, which can be used to explore many different assumptions and estimates. In particular, the probability of health hazard, the magnitude of health effects, the probability of a research breakthrough, and the cost of mitigation were explored for a large range of possible values. The full model is described in Appendix F. Here we describe only its structure and main results.

The Decision Tree

Figure 9.8 shows the decision tree that considers two alternatives: 1) Continue funding special EMF research at an annual level of $R (e.g., at $20 million per year) vs. 2) discontinue special funding of EMF research except for funds available through basic research funding agencies (e.g., $1 million per year). Following this decision are three possible events: The research produces a positive breakthrough, a negative breakthrough, or it remains inconclusive. A positive breakthrough establishes unequivocally that there is a health hazard, without the possibility of a false alarm. Similarly, a negative breakthrough establishes unequivocally that there is no health hazard (for example, by finding a confounder in all previous epidemiological studies), without the possibility of a false rejection. Note that for these conditions to hold, a positive breakthrough can only occur, if there is a health hazard, a negative breakthrough can only occur if there is none. If there is neither a positive nor a negative breakthrough, the research will remain inconclusive.

In the event of a positive breakthrough, the model forces a mitigation decision. Depending on the seriousness of the hazard, this mitigation could involve undergrounding a significant proportion of transmission and distribution lines and to fix wiring and grounding systems in homes. In the event of a negative breakthrough, the only reasonable decision is not to mitigate. In the event of continued inconclusive research, both mitigation and non-mitigation options have to be weighed in light of the probability of a health hazard, the seriousness of the hazard, the cost of mitigation, and other social costs. For example, if the mitigation costs are high, the health risks and other social costs are low, it may be advisable not to mitigate at this decision node in the tree.

The nodes and branches of the tree following the decision to provide special EMF funding are the same as those following the decision not to provide special EMF funding. However, the probabilities and some consequences differ.
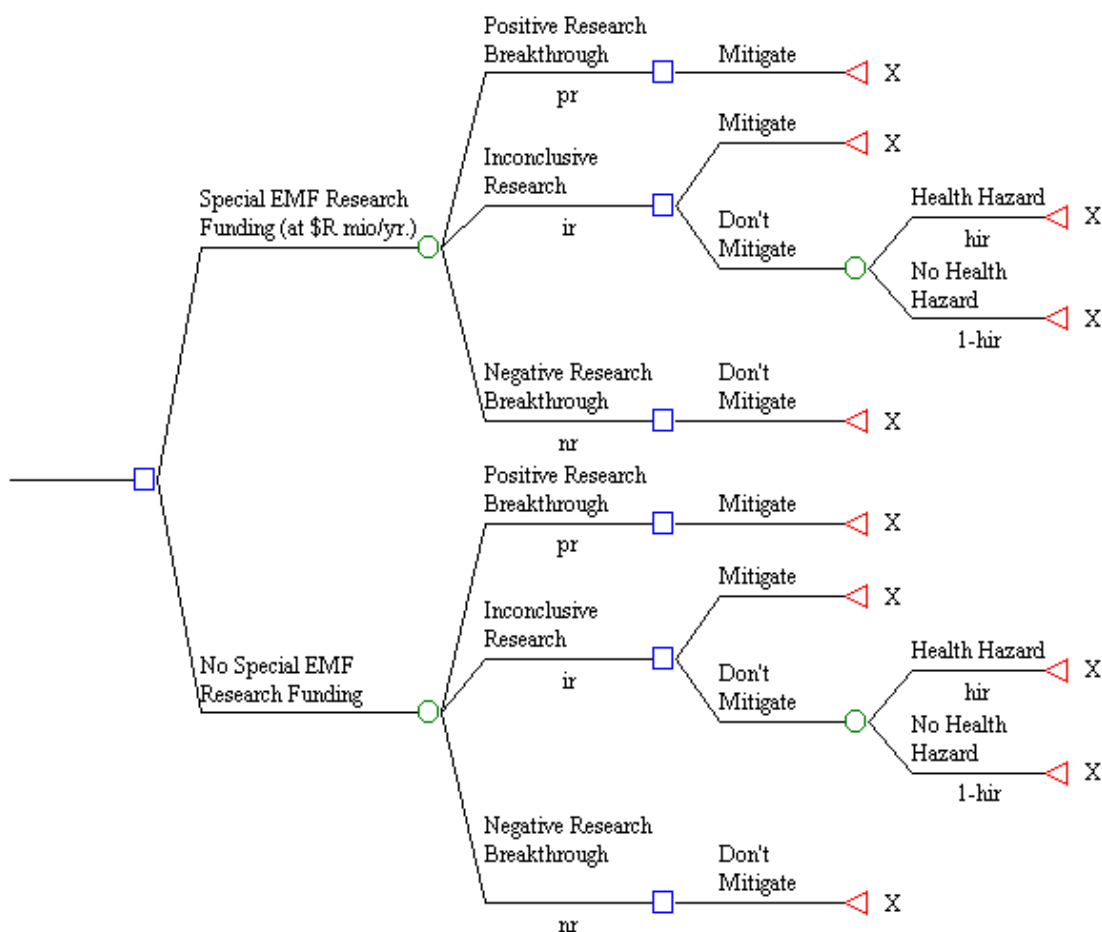
Figure 9.8: Decision Tree for the National VOI Model

Probabilities

The probability of a hazard (he) captures both the probability of a biological response to EMF exposure (which may be fairly high) and the probability that this biological response leads to a significant number of health effects (which may be fairly low). Since experts disagree widely about this probability, we will investigate its effect over a wide range, from he=0 to he=0.50, with a base case of he=0.10.

The probability of a research breakthrough, given a hazard (q) depends on the amount of research funding per year, and the number of years of research. Considering that 20 years of research has not created a research breakthrough, it is not very likely that the next year, or even the next five years will produce such a breakthrough, even if there is

1 a hazard. In addition, the incremental probability of a positive breakthrough should be
2 marginally decreasing as time goes by. To capture these thoughts, we modeled the
3 probability of a positive breakthrough as a function of time t an research funding R. Table
4 1 shows some values of q for t=1 and t=10 and for different funding levels.
5 Corresponding to q(t), the probability of a positive breakthrough, is r(t), the probability of
6 a negative breakthrough. Since it is harder to prove a negative, we defined r as q/2.
7
8 **Table 9.3 Estimated Probability and Time to a Research Breakthrough**
9

Annual Research Funding (Millions)	p(Breakthrough)		Expected Number of Years (Estimate)
	1 Year	10 Years	
1	0.02	0.22	40
10	0.06	0.48	20
100	0.10	0.65	10
1000	0.13	0.77	5

10
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12
13   With these inputs, the unconditional probabilities of research outcomes (pr for
14 positive research, nr for negative research, 1-pr-nr for inconclusive research) and the
15 conditional probabilities of a health hazard, given research outcomes (hir for a health
16 hazard given inconclusive research, 1-hir for no health hazard given inconclusive
17 research) can be calculated as follows:
18
19                $pr = he * q,$
20                $nr = (1-he) * (q/2),$
21                $ir = 1 - pr - nr,$
22                $hir = he * (1-q) / ir.$
23
24 Since q is a function of the research funding level R, the resulting marginal and
25 conditional probabilities will differ for the decision of special research funding for EMF
26 and no special research funding.
27
28 **Consequences**
29
30 At the end of each path through the decision tree in Figure 9.8, one needs to take stock of
31 the various consequences that this path produced. The model considers six types of
32 consequences:
33
34   • R: Annual EMF research funding ($ millions per year)
35   • H: Annual fatalities due to EMF (number per year)
36   • I: Annual illnesses due to EMF (number per year)
37   • M: Cost of mitigation to eliminate health effects ($ millions),
38   • P: Value of appreciated property due to mitigation ($ millions),
39   • S: Annual cost of "social strife" of the EMF controversy ($ millions per year).

Base case estimates and ranges for these consequences are shown in Table 9.4 and discussed below.

Table 9.4: Base Case Estimates and Ranges for Consequences

Variable	Description	Low	Base	High
R	Research Funding (in $ millions/year)	$1	**$25**	$1,000
H	Number of Fatalities/Year Given Hazard	100	**1,000**	10,000
I	Number if Illnesses/Year Given Hazard	500	**5,000**	50,000
M	Mitigation Cost (in $ millions)	$5,000	**$50,000**	$500,000
P	Property Value Appreciation (in $ millions)	$0	**($30,000)**	($50,000)
S	Social Strife Cost (in $ millions/year)	$0	**$100**	$1,000

Annual research funding peaked at about $25 million in the US, and it will likely decline over the next few years. The minimum research funding would be about $1 million, which would be expected from agencies like NSF and NIH. It is hard to imagine funding at a level of $100 million/year or above. The upper range was included in the analysis primarily to explore where research funding loses marginal benefits.

The number of annual fatalities due to EMF will be zero for all paths in the decision tree that end up with "no health hazard" or with "mitigation." At the high end, it is conceivable that there would be thousands of fatalities. Assuming, for example, that EMF is a serious health hazard that doubles the base rate fatality risk of all implicated cancers for people living near power lines and that 2% of the population live near such powerlines, the total excess fatality rate would be 5,000/year. Illnesses include curable breast cancer or other curable cancers and non-fatal diseases like Alzheimer's disease. Illnesses are counted in the model as multiples of fatalities. In the base case we assume that there are five illnesses for each fatality. Thus, illnesses could be as high as 50,000 cases per year.

Mitigation costs depend strongly on the scenarios that define the number of health effects, the mechanisms of a possible EMF-health link, and the knowledge gained by a research breakthrough. For example, if a positive research breakthrough establishes that there are about 1,000 fatalities due to a specific causal mechanism, the mitigation costs would likely consist of selectively reducing ground currents in homes and locally undergrounding transmission and distribution lines, at a cost in the tens of billions. If, on the other hand, the research establishes that there are 10,000 fatalities due to an ill specified mechanism, nothing short of massive undergrounding and elimination of ground currents would do the job, possible at a costs of hundreds of billions.

Powerlines, especially transmission lines, have been associated with reduced property values (Gregory and von Winterfeldt, 1996). Undergrounding these lines will therefore increase property values, even if EMF was not an issue. Assuming that 2% of some 100 million homes in the US are close enough to transmission or distribution lines to warrant undergrounding, and further assuming an average home value of $150,000, a ten

percent appreciation in property values would create $30 billion in property appreciation as a side benefit of undergrounding.

The EMF controversy has produced substantial social strife through law suits, controversies about the siting of new powerlines, etc. Continued research is likely to provide fuel for this strife. It is possible, on the other hand, that eliminating the special research funds will reduce social strife. In the model, we allocate somewhere from no cost of social strife to $100 million/year for the branches that involve continued research, and a corresponding amount reduced by a parametric factor a (base case: a=0.90) for the branches that involve no special research.

Tradeoffs and Discounting

To make all consequences commensurate, they are transformed into 1998 dollars. Mitigation costs and property value appreciation are already counted as 1998 dollars. Research funds and social strife costs are counted in annual dollars. To make these annual dollar streams of research and social strife costs commensurable with the fixed 1998 costs, we discount the cost streams using a rate d, which varies from 0% to 5%. For reference, the federal Office of Management and Budget used a net discount rate of 3.9% for government projects starting in 1996. As a base case, we used 4%.

Health consequences are counted as the annual number of fatalities due to EMF exposure. We first transformed the fatalities into an equivalent dollar cost, using a value of life (VOL) of $5 million per fatality as a base case. This equivalent cost is in the mid-range of public expenses for life-savings programs (see Tengs et al., 1995), which vary from a low of tens of thousands per fatality (for example, for highway safety programs) to tens of millions per fatality (for example, for nuclear power safety).

Next, we discounted the equivalent costs of a fatality by d%. An infinite stream of costs c/year, discounted at d% has a net present value of c/d which is the amount used for 1998 costs. For example, assuming 1,000 fatalities per year at $ 5 million per fatality, the annual equivalent costs are $5 billion. The infinite stream of $5 billion per year discounted at 4% corresponds to $125 billion in 1998 net present value.

It is important to point out that we are not discounting fatalities, but the expenditures to save lives. The choice between saving a life today vs. in ten years is very hard, but the choice between spending $5 million today to save a life today vs. spending $5 million today to save a life in twenty years is easy. Clearly, the $5 million today could be used as an investment to create twice as much money (in real terms at a 4% net growth rate), and thus save two lives in 20 years.

The value of an illness (VOI) is $200,000 in the base case. This cost corresponds roughly to the estimated social costs of one case of Alzheimer's disease. The equivalent costs of the annual number of illnesses are discounted at 4% to calculated an equivalent net present value.

With these ground rules, and using the base cases of Table 3, we now can convert the set of five consequences at the end of each path through the decision tree into 1998 dollars and simply sum up the costs to a total equivalent cost. The formula for calculating the total equivalent cost X for the first year of research funding is:

$$X = R + H*VOL/d + I*VOI/d + M + P + S/d.$$

Results

Figure 9.9 shows the expected cost at each node of the solved VOI decision tree. At the root node, it shows that the decision to fund research at $25 million per year is better by about $500 million than the decision to reduce funding to $1 million of "non-special" research.

The reason for this high value of research is the increased probability of a positive or negative breakthrough. Increasing research funds increase the probabilities of positive or negative breakthroughs and reduce the probability of inconclusive research and, by implication, the probability of a health effect, given inconclusive research. While these changes in probabilities are small, they operate on very large stakes, so that the expected cost differences are still very large in comparison to the cost of research. Note that when research is inconclusive, the best action is not to mitigate. The expected cost of this action is smaller for the "Special Research Funding" subtree than for the "No Special Research Funding" subtree.
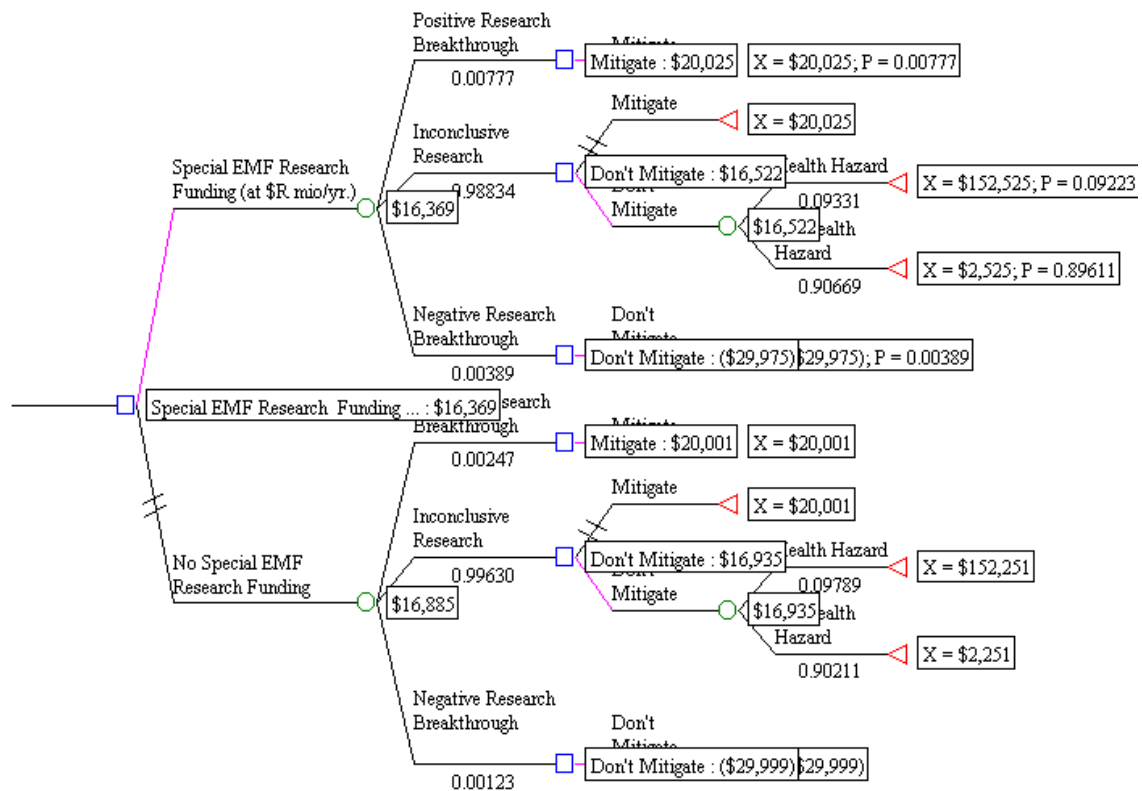
Figure 9.9: Solved Decision Tree for the National VOI Model

Figure 9.10 shows how the expected value of the decision to provide special funding for EMF research varies with the amount of special research funding. The optimal amount (least expected cost) is about $200 million/year. Research funding below about $13 million/year is not worth it, because it does not have sufficient effect on the probability of a breakthrough. Research funding above about $1,200 is not worth it, because it would exceed the marginal benefits of reducing the health and other social costs of learning about the research outcomes.
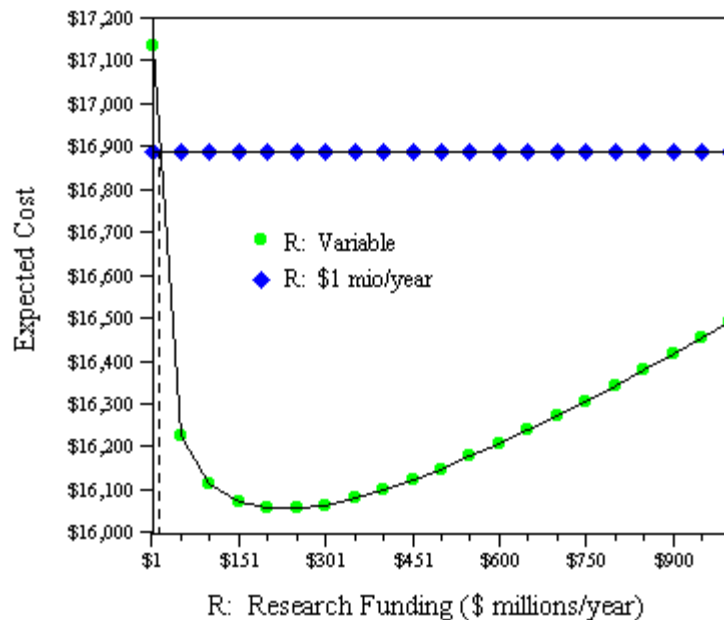
Expected Cost

$17,200
$17,100
$17,000
$16,900
$16,800
$16,700
$16,600
$16,500
$16,400
$16,300
$16,200
$16,100
$16,000

● R: Variable
◆ R: $1 mio/year

$1 $151 $301 $451 $600 $750 $900

R: Research Funding ($ millions/year)

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2
3   **Figure 9.10: Expected Social Cost as a Function of EMF Research Funding**
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5
6   Many sensitivity analyses supported the basic result that EMF research is valuable.
7   For example, when mitigation costs are low (low cost or no-cost mitigation) and health
8   effects are high (1,000 fatalities and 5,000 illnesses per year), the optimal research funding
9   level is $3.5 million per year. When mitigation costs are medium and health effects are
10   high, the optimal research funding level is $40 million per year.
11
12   **9.3 Conclusion**
13
14   Given that 20 years of EMF research has not produced conclusive results, it is
15   perhaps surprising to find that it is worth spending considerable amounts of money on
16   additional research. The reason for this high value of EMF research is, however, fairly
17   easy to understand: As long as the possibility of large numbers of health effects remains,
18   and as long as mitigation is less costly than the health effects, even a small probability of
19   resolving the EMF issue has enormous payoffs. As a rough rule of thumb, the value of
20   research is proportional to the probability of resolving the EMF issue times the difference
21   between health and other social costs and mitigation costs. As long as the difference
22   between the health and social costs and the mitigation cost are in the billions of dollars,

even a very small probability of resolving the issue produces large expected cost reductions.

In addition to the consequences of the research funding decision, two model parameters influenced the value of research strongly. The first parameter is the prior probability of a health hazard. As prior probabilities decrease towards 0.03, the value of research decreases to zero, below 0.03 it remains at zero. It would be interesting to poll EMF researchers to determine the current range of prior probabilities of a hazard. Informal discussions suggest that this probability is substantially higher than 3%.

The second parameter is the strife reduction factor, which indicates how much less social strife is created with no special research vs. special research at a significant funding level. The value of research decreases with this factor and approaches zero when the strife reduction of stopping the research funding is substantial (about 60-70% of the strife generated with special EMF funding). While this factor has a major impact on the value of research, it is also a very speculative item. It is quite unclear, how the much the social strife of doing special EMF research costs, and it is even less clear, by how much this cost can be reduced by stopping the research. One might even argue that the social strife is increased by stopping special EMF research, for example, by leaving the EMF field open to less qualified scientists and occasional dramatic findings that are not carefully reproduced.

On balance, the robust conclusions is that special EMF research funding should be continued, and should possibly increased from current levels. As long as the stakes are high and the chances of a hazard are in the order of 10% or higher, it is clearly worth to pursue the elusive research breakthrough.

A separate question is whether research funds might be better spent in other areas involving health risks. Some might argue that society's research dollars would be better spent on AIDS research, others may favor spending money on developing a cure for cancer. While this argument is logically sound, it is also academic. Research moneys are not spent according to abstract cost-benefit principles, but according to the organization structures that control the funds. Deciding on societal priorities is desirable, but not easily achievable. Furthermore, while EMF research expenditures may not generate the biggest "Bang for the buck," they clearly are more cost-beneficial than other government spending, on research or otherwise.